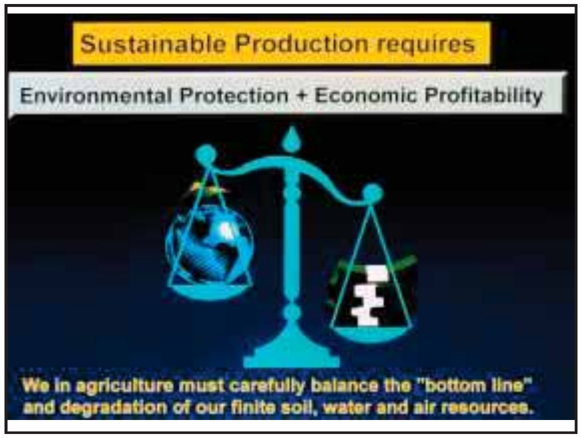
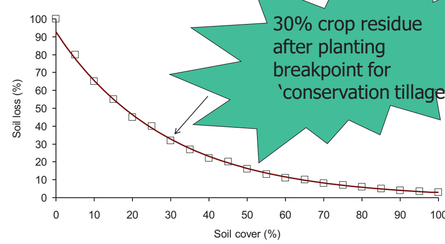
No-Till and Reduced Tillage Options for Dairy Farms

Sjoerd W. Duiker
Soil Management Specialist
Penn State University



Maximum Residue Benefits

Soil Erosion Reduction due to Mulch Cover



30% crop residue after planting breakpoint for 'conservation tillage'

Crop residue (%) for corn after corn

Tillage system	Crop residue cover
	(%)
No-till, plant	56.0a
Blade plow, plant	41.3b
Field cultivate, plant	32.7bc
Till-plant	30.1c
Disk, plant	28.2cd
Disk, field cultivate, plant	20.1de
Blade plow, till-plant	19.7e
Chisel plow, disk, plant	19.1ef
Chisel plow (fall), disk, plant	19.3ef
Disk, disk, plant	17.5fg
Disk (fall), disk, plant	17.1g

No-till or very limited in-row tillage needed to meet minimum residue standards

w/o stalk chopping or knife fertilizer injection. Average of 2 yrs of data

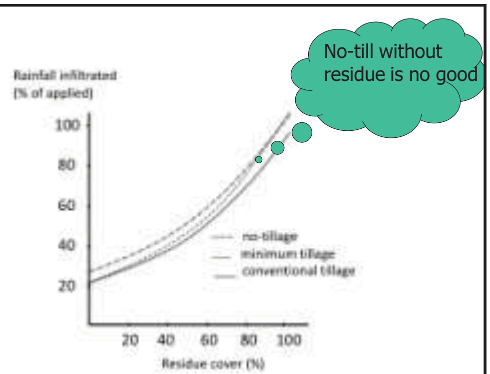
Shelton et al., 1995

Effects of In-Row Tillage on Residue Cover

Tillage	Residue Cover (%)
No-Till	48
Zone-Till	33
Strip-Till	21
LSD	*9.2*

Year 2003

It's easy to reduce Residue cover below desired levels with minimum disturbance



Roth et al., 1988

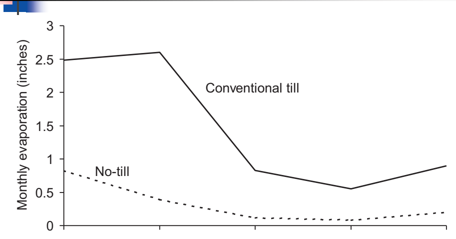
Increase infiltration

Runoff from watersheds (")

	No-Till	Conventional Till
1979	0.1	5.5
1980	0.2	12.5
1981	0.0	5.6
1982	0.4	4.4
Average	**0.2**	**7.0**
Percent of precip	**0%**	**16%**

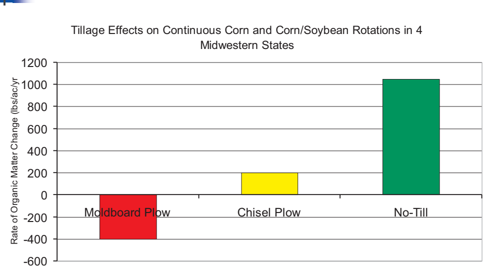
Coshocton, OH, no till was on 9% slope, conventional till on 6% slope. Average rainfall 42 inches

Reduce evaporation

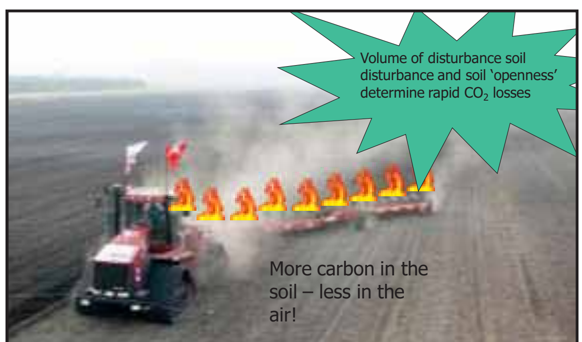


Soil structure improvement

Build Soil Organic Matter by Reducing Disturbance



(1 acre, 6 inches deep = 2 mill lbs. 0.05% ann increase)



A Case IH STX500 Steiger Quadtrac tractor shattered the World Plowing Record by turning 792 acres (321 hectares) of prime farmland near Commensacq, France, in 24 hours, 10.6" deep, 8.7 MPH.

No-till and Biological Activity

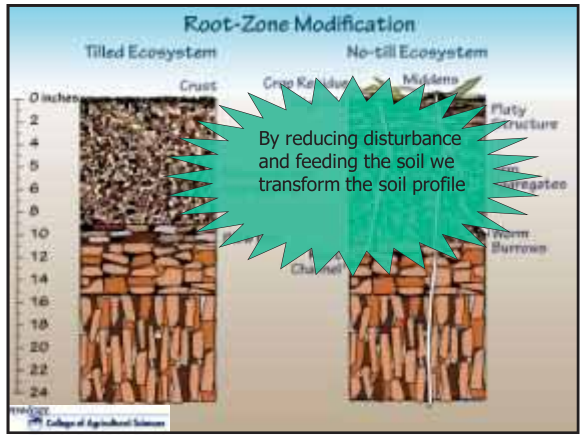
Disturbance and type of 'food' determine biological activity

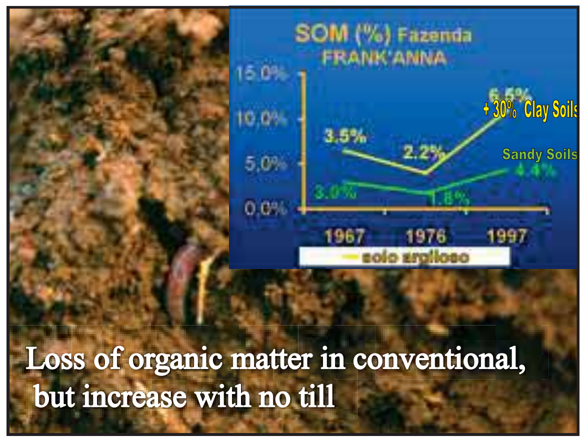
# of earthworms/A

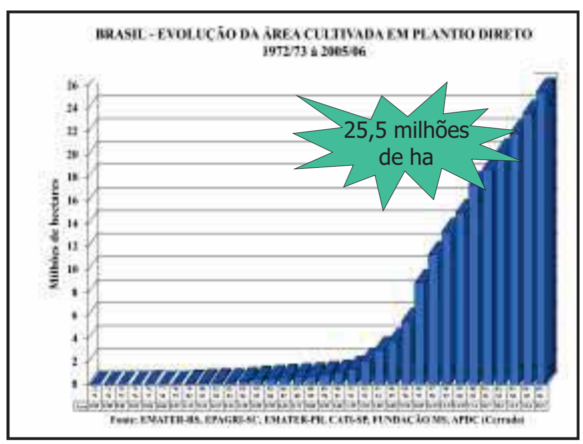
	No-Till	Plow
Cont.Corn	75,000	40,000
Cont. Soybean	500,000	230,000
Clover/Ryegrass	2,000,000	
Pasture+manure	5,000,000	

Data from Indiana
Crop and management systems continuous for at least 10 years

College of Agricultural Sciences





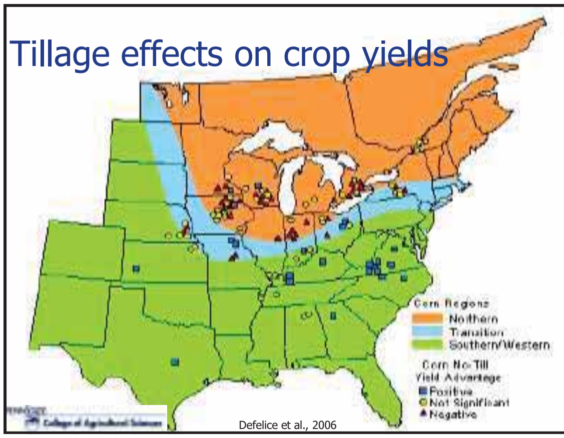


Labor/Equipment S[illegible]
With No-till

Most important benefit for producer is often gains in efficiency and timeliness

Operation	Moldboard Plowing	Chis[illegible]ic	No-till
Plowing	×	×	
Disking	×	×	
Cultipacking	×		
Pre-spraying		×	×
Planting	×	×	×
Post-spraying	×	×	×

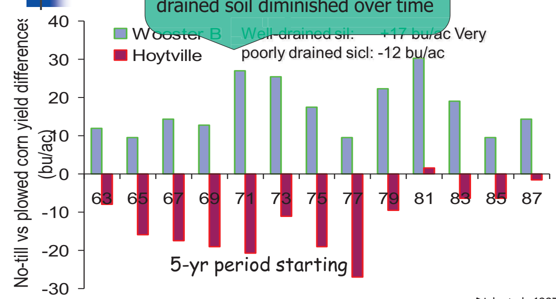
Tillage effects on crop yields



Defelice et al., 2006

Soil
and no-til[illegible]

Great yield improvement on well-drained soil in NE Ohio
Yield reduction on poorly drained soil diminished over time



Dick et al., 1997

Crop rotation
and no-till

Crop rotation took care of cold soil syndrome!

	No-Till	Conv.Till
Continuous Corn	112	125
Corn-Soybean	129	129
Corn/Soy/Meadow	127	133

20-yr average corn yields (Bu/A) on a poorly drained Hoytville sicl, Ohio

Residue Uniformity is Key

Drag chain

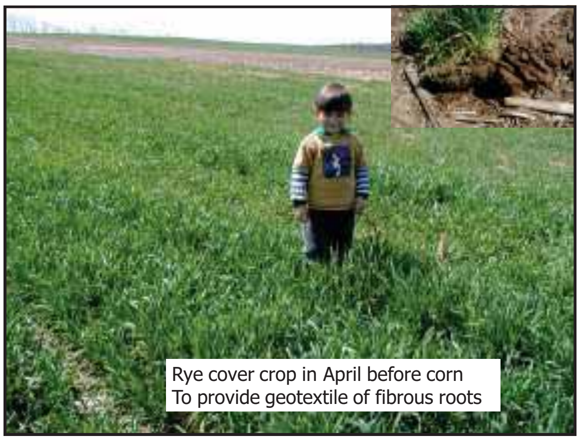
Fluted coulter curved finger residue cleaner combo

Fingered and cast iron closing wheel combo

Drills are a necessity for continuous no-till
- Hay
- Soybeans
- Cover crops

Zone tillage – too wet

Think outside the box – alfalfa/grass hay established in oat cover crop (w/o burndown)



Rye cover crop in April before corn
To provide geotextile of fibrous roots

Parabolic shaped subsoiler

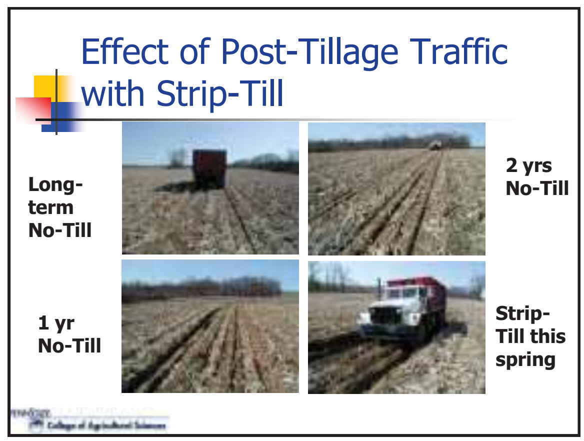
Deep Vertical Tillage

minimum
residue disturbance

	Aim	Philosophy	Effects
School 1	Max fracturing (e.g. DMI, paratill)	Max fracturing between shanks stimulates root growth, infiltration, aeration	Effects of fracturing great immediately after, threat of re-compaction
School 2	Min fracturing (e.g. Unferverth	Roots, water, air will follow channels created by shanks	Effects of fracturing smaller, re-compaction threat smaller


Front coulter, straight shank subsoiler with coulters and rolling basket


Straight shank subsoiler with press wheels


Effect of Post-Tillage Traffic with Strip-Till
Long-term No-Till
2 yrs No-Till
1 yr No-Till
Strip-Till this spring


Very modern subsoilers


Vetch / oat combo
Radish / wheat combo
Oat/radish combo
Cover crop cocktails
To meet specific goals

Houle shallow disk manure injector

Yetter shallow disk manure injector

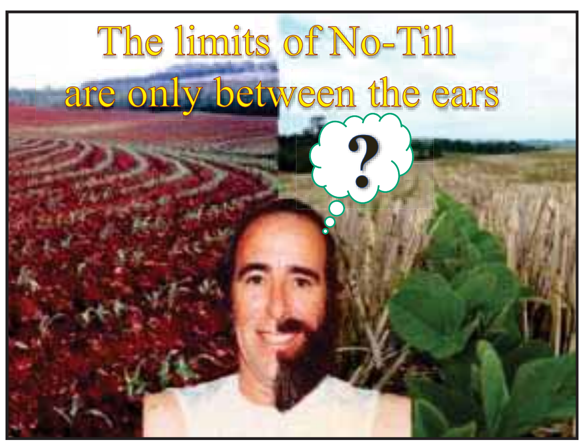
Manure Management in No-Till

Dietrich Manure Unit : shoe type

Genesis Manure system

Take Home Message

- Residue cover – a good thing
- Tillage – eliminate or minimize
- Residue – manage from harvest to planting
- Planter and drill – perfection needed
- Vertical/strip/zone till – use only to address specific needs – mostly unnecessary
- Compaction – stress avoidance and soil resilience rather than remediation
- Manure – manage with cover crops and injection



NO-TILLAGE AND REDUCED TILLAGE OPTIONS FOR DAIRY FARMS

S. W. Duiker
Department of Crop & Soil Sciences
The Pennsylvania State University

NO-TILLAGE BENEFITS

The benefits of no-tillage with high mulch cover are numerous:

1. Soil erosion is reduced as mulch cover increases, leading to maintenance of soil productivity and water quality. Rainfall simulations indicate that on average, soil erosion is reduced 70% if residue cover increases from 0 to 30% (Fig. 1). This indicates that the first 30% of residue cover are especially important. The 30% residue cover threshold is used as the dividing line between conservation tillage and reduced or conventional tillage.

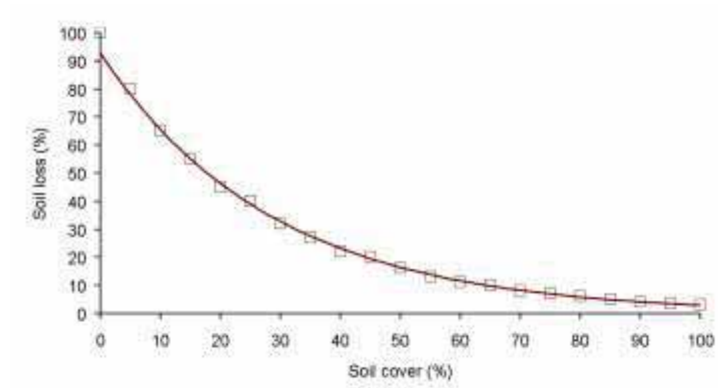


Figure 1. Soil loss is reduced as residue cover increases.

2. Water infiltration is improved and run off reduced, leading to improvements in water quality and crop water use efficiency. Rainfall simulation research in Brazil showed that infiltration increased (and runoff decreased) with residue cover (Fig. 2). In this research, 100% infiltration was only achieved with 100% residue cover. Surprisingly, there was no difference in infiltration between conventional tillage, minimum tillage, and no-tillage, as long as mulch cover was maintained. In practice, of course, residue cover will be reduced dramatically with tillage. The authors of this study recommended therefore high residue cover in no-tillage as the soil management system of choice. Other work under natural precipitation in watersheds in Ohio showed that runoff was dramatically reduced on sloping, well-drained soils if continuous no-tillage was practiced. In fact, runoff was

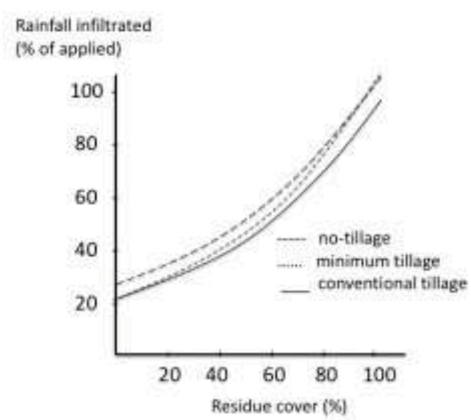


Figure 2. Infiltration increases with crop residue cover. This research was done on a well-drained, well-structured Oxisol in Brazil (Roth et al., 1988).

almost nil in no-till (with almost 100% residue cover) compared with conventional moldboard plowing where 16% of rainfall was lost in runoff over a four-year period (Shipitalo et al., 2000).

3. Water evaporation from the soil surface decreases dramatically in high-residue no-tillage compared with tillage as research from Kentucky shows (Fig. 3). Reduction in evaporation was greatest until canopy closure, but was still very substantial after that as well.

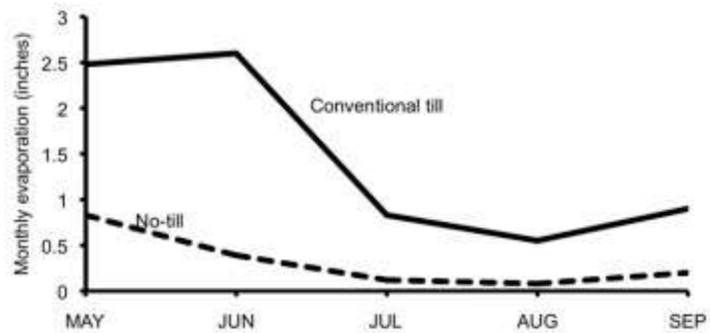


Figure 3. Evaporation from the soil decreases with high-residue no-till, leading to water use efficiency improvement (data from Phillips, 1984).

4. Macroporosity increases in long-term no-till with high residue. This is primarily the result of the increased activity of large soil organisms such as nightcrawlers, but also due to old root channels that remain after the main crop or cover crop is terminated. Some crops such as alfalfa have deep taproots, whereas other (cover) crops such as the ‘Daikon’ forage radish have a large taproot near the soil surface, which tapers down to a smaller diameter 6-8 inches below the soil surface. When these crops die either naturally or after application of a burndown herbicide, but without tillage, the decaying roots leave behind large macropores that provide an access point for following roots, or can be tunnels for aeration and water percolation. Maryland research documented that corn roots followed the old root channels of a previous forage radish cover crop. Pennsylvania research has shown that the root systems of cover crops such as cereal rye reduce the bulk density of the soil in long-term no-tillage. The continuous macropores to the subsoil can help improve the drainage of the soil over time as has been shown in demonstrations where smoke was injected in drain tillage and the smoke blew out of wormholes above the tile lines in long-term no-tillage, in contrast to that in tilled soil.

5. A firm soil matrix leads to improved soil trafficability. Whereas the soil is perforated by many macropores, the matrix between these pores remains firm. The difference in trafficability is remarkable and a definite advantage for long term no-tillers. The firm matrix often results in higher bulk density values in no-tillage than in tilled soil. However, this is not necessarily a problem for soil function. In fact, the lack of continuity of pores in tilled soil is counter-productive.

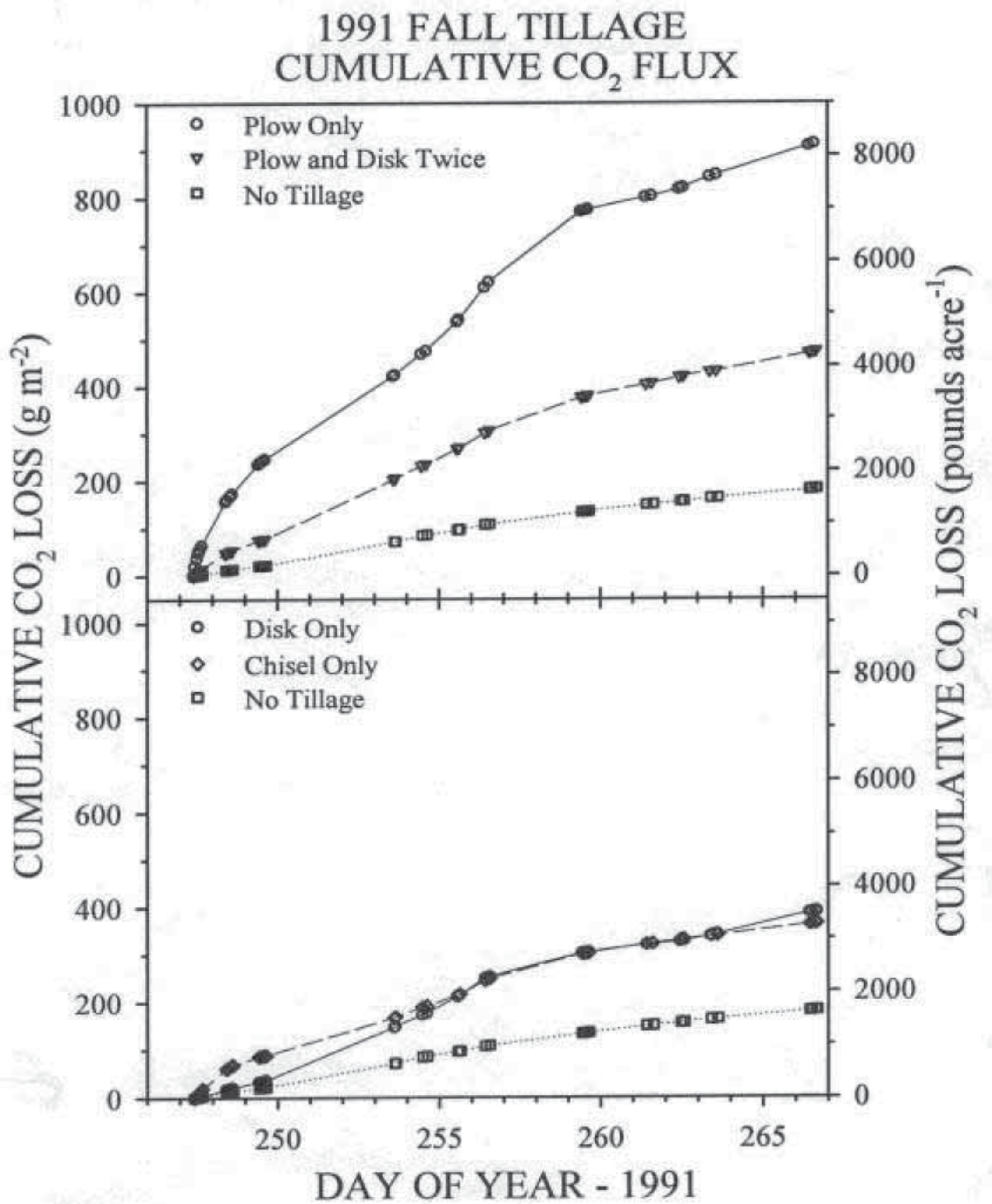


Figure 4. Carbon dioxide release is very quick after tillage and proportional to the volume of soil disturbed (Reicosky et al., 1995)

6. High soil organic matter content near the surface provides compaction control and soil tilth improvement. Near-surface soil organic matter increases in long-term no-tillage due to a few reasons: carbon dioxide is not released quickly from the soil such as after tillage; aggregates are left intact, and organic matter is not mixed into the plow layer. Very high carbon dioxide release has been measured just after tillage. This release has been shown to be proportional to volume of soil disturbance (depth

and level of inversion) as well as how rough the land is left after tillage (Fig. 4). In no-till soil, aggregates are not broken by tillage and organic matter is protected within these aggregates. The lack of mixing leaves the organic matter at the soil surface where it is most important for soil function.

7. Soil aggregation and tilth improves near the soil surface. The humified organic matter has long been recognized as an important ingredient for aggregate stability, but now we are learning that not completely decayed organic matter also plays an important role in aggregate stability, as well as polysaccharide compounds that are released by fungi (glomalin) that act as glues that hold soil particles together. Further, the living roots of crops and cover crops are also important in the maintenance of soil aggregation. Finally, fungal hyphal networks also contribute to aggregate stability.

8. Biological activity increases, the cause of improved soil properties. Soil biological activity is typically double that in no-till soil compared with tilled soil. The number or earthworms is larger because certain types, especially the large nigthcrawlers which make large, vertical macropores that may be 4 feet deep, need crop residue at the soil surface as part of their habitat. In a clean tillage situation these earthworms are highly negatively affected. No-till soil has higher fungal biomass. No-till soil is therefore often called more ‘fungal’ while tilled soils are predominantly ‘bacterial’.

9. As a result of the prolonged use of no-tillage, the soil profile is completely transformed cf a tilled soil (Fig. 5). A tilled soil has a pulverized topsoil which is bare,

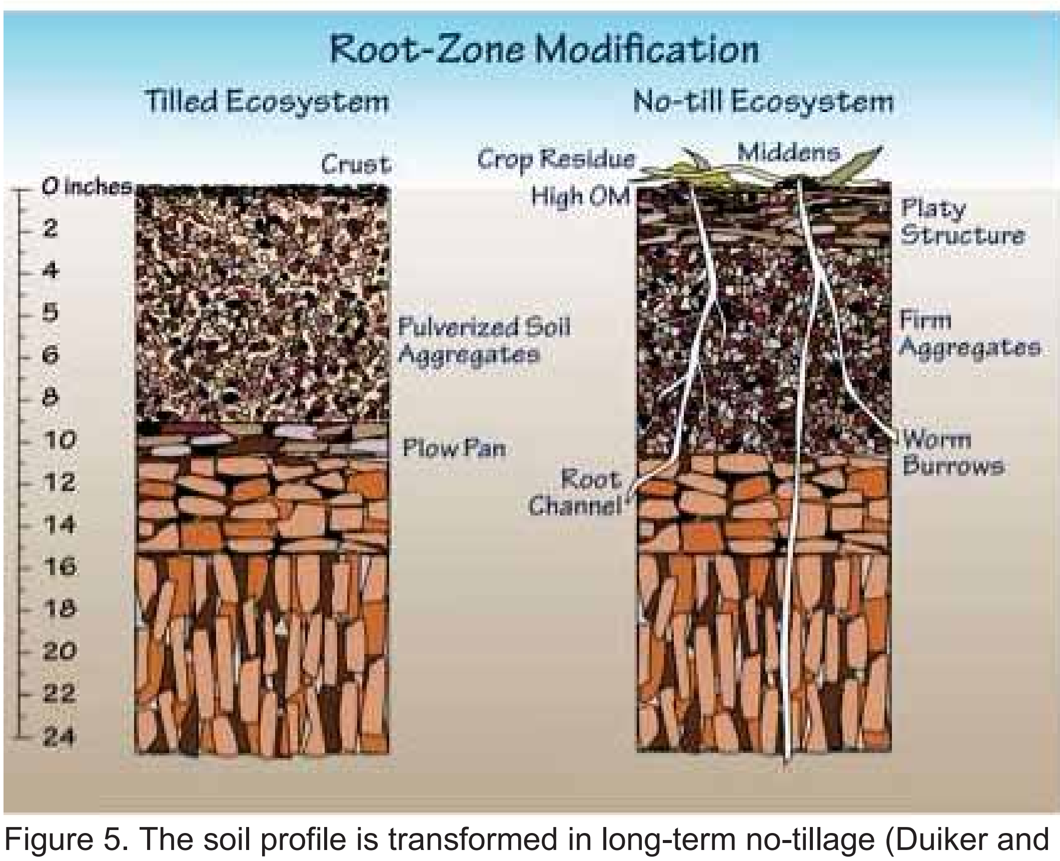


Figure 5. The soil profile is transformed in long-term no-tillage (Duiker and Myers, 2006).

which easily crusts and seals, and has little evidence of macroporosity in the subsoil. In contrast, a long-term no-till soil is covered by crop residue, has high organic matter near the surface, has stable near-surface aggregation, has many continuous macropores, but a firm soil matrix.

10. Labor savings and crop production efficiency improve because many tillage passes can be eliminated. In addition, tillage often delays other activities such as planting. Especially on farms where labor is a scarce commodity, no-tillage can help with timeliness of planting. Another important benefit of no-tillage is the possibility to establish the next crop immediately after harvest. This is impossible with tillage. This opens new opportunities to use cover crops or grow other crops in a double cropping system. It is for this reason that no-tillage is transforming cropping systems, for example in the Great Plains, where the traditional wheat-fallow system is replaced by a more diverse crop rotation.

NO-TILLAGE CHALLENGES AND SOME REDUCED TILLAGE OPTIONS

Despite the many advantages, there are also challenges to no-tillage. The challenges are greatest with corn planted into corn stubble in northern latitudes, and then particularly on poorly drained soils. On these soils, the slower soil warming under heavy mulch may lead to slower germination and early growth of corn. Corn, with its growing point below the soil surface for 4-6 weeks, is especially affected by this phenomenon. Further, the water savings obtained with no-tillage may actually work against one if the soil needs to dry out. The question is, however, what the net effect on crop yield is. A recent review by Pioneer agronomists compared effects of no-till and conventional tillage (fall primary tillage with spring secondary tillage) on corn and soybean yields. The review included 61 corn experiments, representing 678 site-years and 43 full-season soybean trials representing 455 site-years of data throughout the entire United States and Canada. The results of this review showed large yield benefits to no-tillage in the southern and western U.S. where moisture stress is common and temperatures are high. In the northern U.S. and Canada there was a slight yield disadvantage to no-tillage in some trials, although not in all trials (Table 1).

The researchers observed that in some of the studies no-till yield improvement was observed over time, but that the studies had not been in place a sufficient amount of time to have an impact on the yields. Drainage in new no-till plots is often poor until the remnants of previous tillage such as tillage pans and lack of structure disappear. Researchers may also have a learning curve with no-tillage, leading poor results until they start to master the new system. Finally, research studies usually use the same management practices in no-tillage as in conventional tillage, such as weed control, fertilization, and seeding rates and dates, are typically held constant. In reality, however, a producer will have to adjust these factors to have success with no-tillage. The authors remarked that producers practice no-tillage for reasons that include, but go beyond yield: Management costs, farm size, labor and time constraints, soil conservation, and government programs all influence the decision to practice high residue systems like no-till or strip till. Even where a small yield reduction is absorbed the economics of no-tillage and government incentives make this a small economic issue. Other factors, such as environmental stewardship, personal experience, equipment availability, fuel prices, and government incentives will be a far greater influence on the decision to no-till than the effect on crop yield. The authors therefore concluded that more conventional tillage – no-tillage comparisons were not needed, but instead a focus on improving of success with no-tillage.

Table 1. Corn and soybean yield advantage of no-tillage over conventional tillage.

		% Yield advantage of no-till (no. of comparisons)	
		Corn	Soybean
All experiments		-0.5 (104)	0.7 (67)
Geography	Southern/Western	12.2 (26)	5.0 (26)
	Transition	-1.8 (16)	-0.6 (22)
	Northern	-5.5 (62)	-3.9 (19)
Soil drainage	Moderate/well drained soils	2.0 (64)	2.0 (41)
	Poorly drained soils	-4.5 (40)	-1.4 (26)
Crop rotation*	Corn-soy rotation	1.9 (38)	0.7 (40)
	Continuous	-1.5 (60)	1.1 (23)

Reproduced from Defelice et al., 2006.

If a yield drag in no-till is real, some non-inversion in-row tillage such as zone-tillage (typically three-coulter system in front of each row unit, Fig. 6) or strip-tillage (typically a separate tillage operation to create zones in which farmers subsequently plant; Fig. 7) may be beneficial. We evaluated zone-tillage on dairy farms in Pennsylvania but failed to find a positive impact on corn yield. We observed that the crop residue cover to be planted in on many of the dairy farms was very low, and that it was uncommon to meet the 30% residue cover standard for conservation tillage, even when no-tillage was used. This was because in many cases (especially the northern tier) the previous crop was corn silage or fall-killed hay. This research led us to focus on improving no-tillage systems instead of zone-tillage.

Figure 6. Zone tillage system with three coulters in front of each planter unit can help to address early germination issues in no-till

We also evaluated the effect of strip tillage on corn yield, but failed to detect a yield improvement with this system over no-tillage except if we had extreme soil compaction.

We evaluated strip-tillage on well-drained soils and are currently evaluating it on somewhat-poorly drained soils with a seasonally high watertable. One of the problems we often encounter with strip-tillage on poorly drained soils is that it is difficult to match the use of these tools to appropriate soil conditions (i.a., it is too wet for tillage).

Figure 7. A tillage tool used for strip-tillage (left) and residue cover after planting (right).

Figure 8. Examples of vertical tillage tools.

Some new tools that have come on the market to manage heavy residue are ‘vertical tillage’ machines. There is little independent research available to help us evaluate these tools. They are marketed to cut crop residue in smaller pieces, loosen soil, and sometimes smoothen soil. The machines may be run in the fall or in the spring. They usually have two gangs of coulters. The coulters on each gang are commonly spaced at 15”. The coulters can be set to run to different depths (up to 6-8” deep). Some vertical tillage tools can only be run straight, whereas others have gangs with coulters that can be run at an angle from the travel direction. In many cases, farmers will use these tools in the fall to speed up residue decomposition and be able to plant into this without any additional tillage in the spring. The tools will leave much of the residue at the soil surface if run straight, and the additional soil warming is therefore questionable. On the other hand, they may do a lot of disturbance and leave the soil unprotected if run at a steep angle from the travel direction. If the surface soil is very compact, these tillage tools may help alleviate that and stimulate infiltration. The tools do not redistribute crop residue, so they cannot compensate for poor residue distribution after the combine. Because these tools do limited soil inversion, they are unlikely to limit ammonia volatilization from surface applied manure. They may alleviate phosphorus stratification temporarily, where very high phosphorus can build up near the surface in field receiving excessive amounts of manure.

Some other tools that can be seen today are ‘aerators’ (Fig 9). These tools have rotating tines that enter the soil and fracture it to a depth up to 8”. The angle of the gang from the direction of travel can vary from, typically, 0-10^{o}. The steeper the angle, the greater the soil disturbance. When run at high speed and maximum angle, these tools can do substantial soil and residue disturbance. Aerators have found applications to manage manure, where they are mounted on the back of a manure spreader. The manure is dribbled either behind or in front of the tines. If liquid manure is dribbled behind the tines it may enter the soil quickly. If the manure is not viscous (e.g. hog manure) and dribbled behind the tines it will run into the slots and one can expect some ammonia volatilization reduction, as well as reduction of phosphorus stratification.

Figure 9. Aerators used in combination with liquid manure systems.

This brings us to the management of manure in no-tillage. We are not able to expand on this topic in the space allotted to this presentation. However, in general it can be stated that manure injection is beneficial in no-tillage for agronomic and environmental reasons: nitrogen from the manure will be preserved (less ammonia volatilization), phosphorus stratification will be reduced, and odor will be reduced. Preferably, residue cover should be left intact when injecting manure.

Cover crops are an essential component of no-tillage systems, especially on dairy farms. The reasons for this are that frequently insufficient residue is left to provide soil protection, water conservation, and to feed soil organisms. The living root system makes soil resist compaction better, provides erosion control, and takes up nutrients that might otherwise leach to groundwater. The cover crops may also provide some forage value. In Pennsylvania we have a large effort underway to evaluate cover crop mixtures with dairy farmers. More information can be found on-line at: http://pacovercrop.ning.com/.

CONCLUSIONS

Continuous no-tillage with heavy residue cover has many advantages for dairy producers, such as erosion control, water infiltration increase and evaporation reduction, macroporosity improvement, improved soil trafficability, greater soil organic matter content and improved soil aggregation and soil tilth. Biological activity is improved, and the soil profile is transformed to more closely resemble a soil under natural vegetation. Lower labor requirements and improvements in field efficiency are important benefits for producers. Yield reductions, if any, should be small and limited to corn grown after corn in northern regions (especially where soils are poorly drained). Challenges are primarily limited to corn after corn harvested for grain. However, it should be possible to address even these concerns without field-wide tillage. In our experience, residue cover is usually rather too little than too much on dairy farms. The cost savings, erosion control, soil improvement and government programs stimulating farmers to no-till are important reasons for farmers to adopt it besides crop yield. Zone-till and strip-till are some forms of in-row tillage that may help farmers overcome concerns with cold soils or compaction, but in our experience do not lead to yield improvement. Vertical coulter tillage or aerators are still under evaluation. Before adopting these tools they need to be closely evaluated on their own merit. Cover crops are important in no-tillage systems, especially on dairy farms. They help the producers realize the agronomic and environmental benefits of no-tillage. In Pennsylvania we are evaluating cover crop mixtures for environmental improvement but also for forage value. You can follow our project on-line at http://pacovercrop.ning.com/.

REFERENCES

Defelice, M.S., P.R. Carter and S.B. Mitchell. 2006. Influence of tillage on corn and soybean yield in the United States and Canada. Online. Crop Management doi:10.1094/CM-2006-0626-01-RS.

Duiker, S.W. and J.C. Myers. 2006. Steps toward a successful transition to no-till. The Pennsylvania State University, University Park, PA.

Phillips, R.E. 1984. Soil moisture. In: R.E. Phillips, and S.H. Phillips (eds.) No-tillage agriculture: Principles and practices. Van Nostrand Reinhold Company, New York. pp 66-86.

Reicosky, D.C., W.D. Kemper, G.W. Langdale, C.L. Douglas Jr. and P.E. Rasmussen, 1995. Soil organic matter changes resulting from tillage and biomass production. Journal of Soil and Water Conservation 50:253-261.

Roth, C.H., B. Meyer, H.-G. Frede and R. Derpsch. 1988. Effect of mulch rates and tillage systems on infiltrability and other soil physical properties of an Oxisol in Parana, Brazil. Soil and Tillage Research 11:81-91.